HWG:LBT:LTQ
VIII-O

DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
204

July 14, 1926

METALS DO NOT "CRYSTALLIZE" UNDER VIBRATION.

This Bureau is often called upon by other government departments to examine failures of metals and alloys which have been subjected to repeated stress, or in reply to inquiries from the general public to discuss such failures. Even though the inquiries come from engineers of standing, the failures are quite generally referred to as "failures from crystallization".

Popular advertising carries many references to "crystallization", as the source of failures of metal parts. The misconception that the crystalline structure of a metal changes as a result of repeated applications of load and that a deterioration takes place which is evidenced by a "crystalline" fracture, is as widespread as it is erroneous. As a recent editorial[1] phrased it, "Staybolts fractured in service have

1. Iron Age, Vol. 117, 1926, p. 1663.

that characteristic appearance known as 'crystallized metal' to the mechanic or 'fatigue failure' to the metallurgist". However, it is not only the mechanic but often the engineer and especially the advertising man who falls into this error.

This erroneous phraseology is altogether too common and greatly hinders general understanding of the real causes of fatigue failure and should never be used.

This letter circular is therefore prepared to summarize the evidence, obtained by competent metallurgists and engineers, which conclusively proves that failure of a metal by repeated stress, vibration for "fatigue", is <u>not</u> due to a change in its crystalline structure.

Foremost among the workers in the study of repeated stress is Prof. H. F. Moore of the University of Illinois who says[2]

2. The fatigue of metals - Proc. Eng. Club of Philadelphia, Vol. 36, 1919, p. 138.

"under repeated stress a shaft may suddenly snap off with almost no warning and part of the fracture frequently appears bright and crystalline. This led to the old theory, NOW DISCARDED, that under repeated stress metal 'crystallized' and became brittle." Again, he says[3] - "The earliest attempt-

3. Investigation of the fatigue of metals, series of 1923, Bull. No. 142, University of Illinois, Bulletin Vol. XXI, No. 39, 1924, p. 9.

ed explanation of the fatigue of metals under repeated stress was the theory of failure by "crystallization", which probably arose from the crystalline appearance of planes of rupture at fractures in metal parts which failed under repeated stress. This crystallization theory was based on the idea that under repeated stress metal changed from a material more or less 'fibrous' to a material having a crystalline structure, and that this crystalline structure made the metal brittle, which therefore, under a load tended to snap apart along planes between the crystals which are formed under repeated stress. THIS THEORY HAS BEEN THOROUGHLY DISCREDITED."

Still again he says[4], - "The old idea was that under

4. Investigation of fatigue of metals under stress, - Am. Inst. Min. & Met. Eng. - Separate, No. 1075 M, June, 1921, p.1.

repeated stress the metal changed its crystalline structure. I do not know of any evidence in favor of the theory that metals materially change their crystalline structure under repeated stress."

He explains this still more fully in another place[5]

5. Investigation of the fatigue of metals - Bull. No. 124, University of Illinois Bulletin, Vol. XIX, No. 8, 1921, p. 151.

"If the fractured surface of a 'rotating beam' specimen made of ductile metal and broken by repeated stress is examined, it is usually seen to be made up of two parts: (1) near the extreme fibers there is a dark surface with a dull, lusterless appearance, while (2) the remainder of the surface has a bright crystalline fracture. If these are examined more carefully, it is found that their principal difference is in the size of the small flat surfaces that constitute the fracture.

The center portion of the area has comparatively large surfaces, giving a crystalline effect, while the dull gray portion has very small surfaces of fracture.

"An explanation of this is that the flaws in the outer portion of the surface have connected to form an annulus, whose rugged face is roughly at right angles to the axis of rotation. This has doubtless occurred slowly, and has started from many centers, thus giving the rough face. After this slow growth of flaws into an annular fracture has been accomplished the specimen has become very weak and the stresses have become so large at the fracture that they suddenly tear the metal in two on the natural surfaces of cleavage of the crystal grains.

"The center portion of this fractured surface does not differ from the crystalline surface at the bottom of a cup in an ordinary static tension fracture, except that the crystalline surfaces are somewhat larger. This is to be explained by the fact that in an ordinary tensile test the material at the fracture has elongated something like 100 per cent, so that the crystal grains have become of smaller cross-section and will naturally show smaller facets on fracture, whereas, in a fracture of the endurance specimen, the material has had no chance to elongate and the crystalline grains have their normal size, which will be shown in fracture. It is not the crystalline portion of the broken specimen which has failed primarily by repeated stress, but the dull portion. In the crystalline part of the fatigue fracture and in the crystalline part of the static tension fracture the failure seems to be of the same nature, namely, a failure in cohesion".

R. R. Moore of the Engineering Division, Army Air Service, describes[6] the effect of repeated impact with varying

---

6. Resistance of metals to repeated static and impact stresses - Proc. Am. Soc. Test. Matls. 24, Pt. 2, 1924, p. 572.

---

intensities of blows. He says - "In the short test the fracture appears crystallin, covering almost the entire fractured surface. As the blow is made lighter and the test lengthens, the crystallin area becomes smaller and the fine grain area becomes larger. This crystallin fracture is characteristic of sudden failure (on this particular steel and heat treatment) and is still visible in the one million blow test indicating the location of the final parting of the metal, which is sudden. If the test is run at still lighter blows until the impact en-

durance limit is reached, it is likely that almost all traces of crystallinity will disappear and the fracture will be very much like that of a static fatigue failure. Evidences of this are already apparent in the million-blow test where the crystallin region is only a thin line which does not extend entirely across the face of the fracture.

"These fractures are additional but probably unnecessary evidence against the old theory of failure by crystallization. THE CRYSTALLIN FRACTURE IS NOT THE CAUSE OF SUDDEN FAILURE AS WRONGLY INTERPRETED IN THIS THEORY BUT RATHER THE RESULT OF SUDDEN FAILURE AS CLEARLY SHOWN HERE."

H. C. Knerr of the Naval Aircraft Factory says[7] -

- -

7. Remarks on fatigue failures of metal parts, their cause and prevention - Forging and Heat Treating, Vol. 8, 1922, p. 40.

- -

"It was formerly thought that fatigue failures occurred by the 'crystallization' of the metal, on the supposition that the structure of the metal changed under repeated stress from a ductile fibrous state to a brittle crystallin one, or that the originally fine crystals grew to coarse ones. Microscopic examination has shown this to be untrue. The structure of steel, iron, and all common metals of construction is fundamentally crystalline, not fibrous. Repeated stress may cause a breakdown of the crystals at the point of failure, but never a growth."

D. J. McAdam, Jr., of the Naval Experiment Station, says[8] -

- -

8. Endurance properties of metals - Mechanical Engineering, July, 1925.

- -

"Failures of metal machinery parts after subjection to many cycles of a range of stress are known as 'fatigue' failures. Such fatigue failures exhibit a characteristic type of fracture; the fracture is highly localized, the adjacent regions show little if any evidence of deformation, and part, at least, of the surface of fracture often appears crystalline.

"The highly localized, often crystalline, fractures observed after fatigue failure led to the theory that such failures are due to 'crystallization' of the metal. By

means of the microscope this theory WAS LONG AGO DISPROVED. We know that all metals are crystalline and we know that subjection to a range of stress does not cause recrystallization of the metal or growth of the crystals. Nevertheless it is surprising how the erroneous idea of failure by 'crystallization' still persists, even among technical men. Within the past few months the Naval Experiment Station has received an inquiry from the metallographist in regard to 'crystallization' by fatigue. An inquiry has also been received from the superintendent of motive power of a large railroad for information about the life of axles. He contemplated placing a definite time limit on axles in service and removing them before they "crystallized" and failed."

Various workers in other countries make similar statements. H. J. Gough of the National Physical Laboratory of England, says[9] - "That failure under repeated stresses was

---

9. The fatigue of metals - Scott Greenwood and Son, London, 1924, p. 187.

---

due to the "crystallization" of the metal was conclusively disproved by the work of the physical metallurgist and, later, by the X-ray analysts of metals."

Prof. L. Bairstow of the Imperial College of Science and Technology says[10] - "So far as the writer is aware,

---

10. The fatigue of metals - Beama, Vol. 11, 1922, p. 734.

---

there is no evidence of recrystallization in iron and steel as a result of fatigue, in spite of a general impression to the contrary."

F. Rittenhausen and F. P. Fischer[11], of the Krupp works

---

11. Repeated stress failures of construction steels and their relation to the Krupp repeated impact test - Stahl und Eisen, Vol. 41, 1921, p. 1681; Forging and Heat Treating, Vol. 8, 1922, p. 519.

---

at Essen, Germany, say, "Numerous researches have proven the untenableness of the theory that repeated stresses cause a change in the structure of steels and thereby changes in their strength and toughness."

To accomplish true recrystallization in steel it is necessary to heat it, as is done in the annealing of steel castings. Every time steel is heated or cooled through its "critical range" its crystal structure changes. But the critical range of the commercial steels is at such temperatures that the steel must be more than red hot before it changes.

Severely cold worked steel, such as cold rolled strip recrystallizes on heating, the broken and distorted crystals reforming into new crystals, but in even the most severely cold-worked material quite high temperatures must be reached, e.g., iron must be heated to around 850°F, and copper to 400°F.

Even steel hardened by quenching, which softens on heating, does not visibly change its crystal structure without heating. The term "Crystallization" should therefore never be used, in reference to the effect of repeated stress, but only in reference to those cases where actual, and not merely imagined, changes in crystallization occur.

The "fatigue" failures that are erroneously ascribed to crystallization are due to exceeding the stress the material will endure. At stresses about the endurance limit, damage begins, finally resulting in the formation of tiny cracks within the crystals, which cracks grow larger as the stress is repeated and finally cause failure. It may take millions of cycles of stress to develop this damage so that it is apparent to the eye, or the microscope, as a crack.

Poor fillets, sharp corners, tool marks or grinding scratches, non-metallic inclusions, as in "dirty" steel, and corrosion or rusting all make for high local stresses. If, at any point the local stress rises too high, damage will be done which will ultimately develop a crack and cause failure. But the deterioration is not connected with any change in crystal structure, nor, short of the development of a crack, can it be detected by metallographic examination.

Magnetic methods, so far, also fail to detect changes in material in the process of failure due to repeated stress - (See Bureau of Standards Technologic Paper 315, Vol. 20, 1926, p.515).

Avoidance of failure under repeated stress must be based upon information as to the endurance limit of the material used, and upon such design of the parts to be subjected to repeated stress as to avoid the stressing of the parts, even in the most minute portion, above that endurance limit. For information on the "fatigue", or repeated stress problem, the publications of H. F. Moore, R. R. Moore, D. J. McAdam and H. J. Gough, some of which are referred to herein, should be consulted.